SPECTROSCOPIC PROOF OF THE REPULSION BY THE SUN OF GASEOUS MOLECULES IN THE TAIL OF HALLEY'S COMET.

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1. The return of Halley's comet has been noteworthy chiefly for the possibility of employing upon it modern methods of instrumental research. Since its last previous apparition have been devised those two great engines of astronomic exploration, spectroscopy and celestial photography. The former has afforded us our first direct knowledge of the substances composing comets, while the latter has given us a means of easy and rapid registration of the visitant's appearance. This is especially valuable in the case of a body as vast and vague as a comet, free-hand drawing of which is peculiarly liable to distortion.

During the last return of Halley's comet that body was subjected at Flagstaff to investigation by both instruments simultaneously. One result of this was the detection that gaseous molecules—in contradistinction to minute solid particles merely—are directly repelled by a force emanating from the sun, presumably the pressure of light. Previously this had been held impossible. Schwarzschild had, as he thought, demonstrated mathematically in an able paper that molecules of gas were too small to be thus affected by the forces concerned and Arrhenius had adopted his deduction and published it as a fact in his "Worlds in the Making." That the bodies themselves would so soon refute this would not have been deemed probable and invests the detection with the more immediate interest. Incidentally we may remark that Schwarzschild had since given up his original opinion.

2. That the tail of a comet is due to repellant force exerted by the sun is apparent from the direction the tail takes. For that direc-

tion agrees with what would be shown by particles leaving the nucleus and travelling in hyperbolic orbits away from the sun, the sun being in the full or the empty focus according to the speed of recession.

Although the general fact is thus evident, to measure the recession directly is to obtain both an observational proof of it and also something approaching an exact value of the velocity at a given time and place. Accordingly I determined to do this in the case of Halley's comet at its recent apparition. At my disposal were the two hundred photographs taken of it at the Lowell Observatory between April 18 and June 6. To obtain trustworthy results the photographs to be compared must not be separated by too long an interval, since with time a general commingling of the various particles takes place which not only renders particular decipherment of different outbursts impossible but entirely alters the actual speeds. In the case of Halley's comet this difficulty was enhanced by the unusual uniformity of the tail. Irregularities, bunches or knots were rare; the tail presenting as a rule, a remarkably orderly deportment, dishearteningly same. Among the many plates, however, I was able to select a pair taken seriatim capable of recognition and measurement. Some of these handles to investigation were in the nature of bunches of matter, some of abrupt changes in its direction looking like promontories along the general line of the tail. I chose four of the more salient excrescences and selecting identical features of them in the two negatives measured their respective distances from the nucleus on the two plates. The first plate was exposed from 9h 23m to 9h 53m and the second from 10h 0m to 10h 53m, so that the one followed directly on the other.

When the angular amounts of the changes in place of the several knots were corrected for differential refraction and then reduced to speeds, account being taken of the distance of the comet from the earth and of the inclination to the line of sight of the respective positions along the tail, the results came out as follows:

From these measurements the fact emerges unmistakably that a repulsive force directed away from the sun acted upon the particles on the tail.

TAIL OF HALLEY'S COMET.

	Angular Distance from the Nucleus to the Point Measured in the Tail.	Velocity of the Point of the Tail Away from the Nucleus.
Knot 1	1° 28′	13.6 miles a second
Knot 2	3° 12′	17.2 " " "
Knot 3	4° 36′	19.7 " " "
Knot 4	6° 15′	29.7 " " "

3. While the series of direct photographs was being taken two series of spectrograms were being carried on by Dr. Slipher, one with an objective prism; the other set through a slit. The objective prism ones recorded simultaneously the spectrum of the nucleus and head, together with that of the tail out to about 11° from the nucleus. One of them was got on May 23 at the same time as the photographs measured; while others were obtained on dates before and after. Of the direct information afforded by these spectrograms of the constitution of the comet an account is given in the extensive monograph on the comet published by the Lowell Observatory.

4. But a third result was obtained by the unwitting collaboration of the spectrograms and the photographs. While the photographs were giving their pictures of the tail, the objective prism spectrograms were doing the like, with this difference that they recorded in a row pictures of it in the several colors of the spectrum, sifting out into a band those made by each separate wave-length of light. They thus made it possible to tell to what wave-lengths the visible appearances were due. For it became evident at once from the spectrograms that all wave-lengths were not equally concerned. On the contrary, there were in the spectral image several distinct tails with spectral gaps between. By an analysis of the wave-lengths yielding pictures of the tail was thus offered a diagnosis of the substances composing it. In this way it appeared that CO_2, carbon monoxide, was the chief constituent of the tail; CH_4, marsh gas, another; CN, cyanogen, a third component; and minute solid particles, giving a more or less continuous spectrum, a fourth.

That not one but a series of spectrograms was taken was important. It not only gave us a constitutional history of the tail but it showed the necessity of simultaneity in photographic and spectrographic observations for comparative purposes. For the series demonstrated that the constituents of the tail varied markedly from one period to another. Thus from April 29, 1910, to May 7 the spectrum of the tail was almost wholly emissive. On May 11 it had changed to one nearly continuous, while on May 23 it had become largely emissive again and grew more so as time went on.

By comparing the photographic with the spectrographic series of representations of the tail a striking fact came to light. To appreciate this another point must be taken into account. In order to compare properly a photograph and a spectrogram, both should be made on the same brand of plate. No plate reproduces all parts of the spectrum with equal intensity. One kind of plate will emphasize certain rays and depreciate others; the next will reverse the estimation. Great error will then be introduced unless the plates be identical.

Now the photographs measured were taken with a Brashear 5-in. doublet, an excellent lens, on a Lumiere Σ plate. The rays registered by this plate extend from 3500 in the violet to 5160 in the green where the sensitiveness ceases. Indeed the effect would have stopped sooner had it not been for the hydrocarbon emission at this point. The light, therefore, of the photograph would be exactly differentiated into its constituents by a spectrogram taken on a Lumiere Σ plate. The only difference between the two would be due to the absorption of the objective prism, an absorption relatively greater for the violet than for the blue or green. This would work as much on one kind of light as on another of the same refrangibility and as the two different kinds we are considering, the emission and the continuous spectrum, are about equally spaced in the region of the violet, the correction needed on this account is small. We may, then, directly gauge the character of the photograph's light by that of the objective prism spectrogram taken on the Σ plate.

This we now proceed to do. On the exact date of the photograph no Σ plate was used with the two objective prisms though we have objective prism spectrograms on Cramer Iso. Instantaneous on May 23, 25, 26, 28 and 29. The nearest plate to the date in question was on May 29. Of this the best estimate gives for the constituents of the light of the tail at a distance of 3° to 6° from the head:

80 per cent. of emission bands of carbon monoxide,
20 per cent. continuous spectrum,

the hydrocarbon emission being, at this distance from the head too feeble to show.

Comparing now the spectrograms taken with a Voightlander lens and a Cramer Iso. Inst. plate on May 23, 25, 26, 28 and 29 we find that the ratio of the two kinds of light varied in the direction of relatively greater emission from the former to the latter date. On May 23 itself the plates are affected by moonlight so that a direct comparison of the relative ratios is too difficult to be made a basis of direct comparison, but that of May 28 gives for the ratios in the tail 3° from the head:

70 per cent. emission of carbon monoxide,
5 per cent. emission of hydrocarbons,
25 per cent. continuous spectrum.

Putting these facts together we shall not be far out of the way in stating the ratio on May 23 of the emissive and continuous spectrum of the tail at a distance of from 3° to 6° from the head for the Σ plate as

70 per cent. emission spectrum, CO and CH_4,
30 per cent. continuous spectrum.

We have then this interesting conclusion: that the knots which showed the action of a repulsive force exerted from the sun were chiefly composed, not of solid particles, but of *molecules of gases.*

5. To clinch this deduction I next turned to comet Morehouse. Catechized in this connection it not only corroborated the fact but emphasized it. Before the time of measuring the velocities in the tail of Halley's comet I had done the like for comet Morehouse, the knotted character of its tail offering promising inducement. I was not aware that Mm. Quenisset and Baldet, in France, and Professor J. A. Miller, of Swarthmore, Pa., had measured photographs of this comet in this manner previously and detected the same accelerated motion away from the head which my own later measures showed. My measures have also revealed why certain previous observers such as Barnard at Yerkes and Campbell at the Lick had failed to find such evidence.

Of comet Morehouse this observatory possesses about sixty negatives taken by Mr. E. C. Slipher. Among them are many pairs, the one plate following the other on the same evening. From the assortment thus offered I have selected two sets for measurement, the one a pair taken on October 31, 1908, at 8h 0m ± to 8h 42m ± M.S.T. and from 9h 14m ± to 10h 8m ± respectively; and the other a triplet on November 16, 1908, No. 1 being taken at 6h 25m to 7h 13m; No. 2 at 7h 24m to 7h 50m; No. 3 at 8h 0m to 8h 32m, respectively. I chose four knots on one and five on the other with the following results:

Tail of Comet Morehouse, October 31.

	Plate I., Distance Knot from Head.	Plate II., Distance Knot from Head.	Difference I. and II.
Knot 1	22′.8	24′.4	1′.6
Knot 2	72′.7	76′.2	3′.5
Knot 3	95′.5	99′.4	3′.9
Knot 4	128′.4	134′.6	6′.2

Tail of Comet Morehouse, November 16.

	Plate I.	Plate II.	Plate III.	Diff. I.–II.	Diff. II.–III.
Knot 1	48′.7	49′.9	51′.4	1′.2	1′.5
Knot 2	63′.4	65′.4	66′.9	2′.0	1′.5
Knot 3	79′.7	81′.6	83′.5	1′.9	1′.9
Knot 4	87′.8	89′.3	90′.9	1′.5	1′.6
Knot 5	211′.1	215′.0	217′.7	3′.9	2′.7

6. It will at once be seen that both sets of plates show accelerated velocity in the particles of the tail away from the head as the distance from the head increases. In the first set the acceleration is fairly uniform, while in the latter the velocity does not increase until the distance out has become considerable. This affords the reason why some observers have failed to detect the motion. It is at times and in certain places masked. For this the following explanation may be offered: In the neighborhood of the head the several emissions are violently contorted as a mere inspection of the photographs show, and in consequence must be subject to collision with other portions of the tail. Possibly they encountered here matter in space which speaks unspeakably of motion other than that due solely to repulsive force. If now an observer chanced to make his measures

at this inopportune moment he would naturally conclude that no repulsion existed while in truth another motion was temporarily obstructing it.

7. Lastly the spectrograms and spectroscopic observations of Frost and Parkhurst, de la Baume Pluvinel and Baldet agree in showing the light of the tail of Morehouse's comet to have been due practically wholly to emission; in other words to glowing gas. Here, then, we have not only corroboration of the fact, brought forward from study of Halley's comet, to wit: that molecules of gas are repelled by the sun, but, from the light of the tail being composed solely of gaseous molecules, any supposition that they were not the cause of the visible effect, is entirely excluded.

We reach then this interesting conclusion: that molecules of gas not only may be but demonstratedly are repelled by the action of the sun and that though we have reason to suppose that minute solid particles may be similarly impressed it is of the former not the latter that we have direct proof at present.

Lowell Observatory,
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